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Original communication

The value of the anthropometric parameters of the tibia in the forensic identification of the Iranian population over the age of 20

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ABSTRACT

Objective: Tibia is one of the bones which can be applied in sex determination in addition to its successful role in determination of stature. The aim of this study was to investigate the value of anthropometric parameters of the tibia in forensic identification.
Materials and Methods: Cross-sectional analysis of anthropometric parameters of the tibia was done by Legal Medicine Organization of Tehran, Iran studying Iranian population over the age of 20 during 2009 and 2010.
Results: This study covered four aspects of tibias of 80 fresh Iranian cadavers, 40 men and 40 women, including the maximum lateromedial length, medial length, proximal width, and the distal width. The study showed that genders can be distinguished using the lateromedial length with 90% sensitivity and 80% specificity, the medial length with 90% sensitivity and 85% specificity, the proximal width with 85% sensitivity and 87.5% specificity, and the distal width with 67.5% sensitivity and 75% specificity.
Conclusion: In order to determine the relationships between the diverse aspects of tibia, the correlations between different dimensions of tibia were examined, resulting in the regression equations between its length and width.

1. Introduction

Cadavers that are sent to forensic medicine departments are not always intact. Sometimes due to air crashes, natural disasters, explosions and other incidents, only the skeletal remains or body parts of the corpse are available for identification.[1] In these cases, sex determination is one of the important criteria.[2] On the other hand, previous studies show that various populations are different in size and skeletal symmetry which can influence the sex evaluation.[3] Although initially the morphological measurements of skeleton were applied for sex determination, scientific metric measurements were considered afterward. The metric method is based on the relationship of the long bone to the stature of an individual and can be done even if a single long bone is available for examination. Metric measurements are preferred due to their easy repeatability, high precision, and needing no special skills.[4]

When the pelvis and skull bones are unavailable, sex is recognized via long bones because they have high accuracy in determination of gender.[5] Tibia is the second biggest bone in the body after the femur; therefore, it is relatively resistant to animal attacks and decomposition. Moreover, based on the results of previous studies, obvious gender differences exist in this bone.[6,7] Additionally, sometimes bones including the tibia are crushed because of accidents and natural disasters and only small pieces of them such as the proximal or distal ends of the bones are available. If we could obtain a significant relationship between these parts' dimensions and the bone length, we could predict the approximate length of the bone and consequently the approximate stature of the person using some calculations. Considering the aforementioned issues and the effects of other factors such as race and geographical region,[6] this study was conducted on the tibia of Iranian population.

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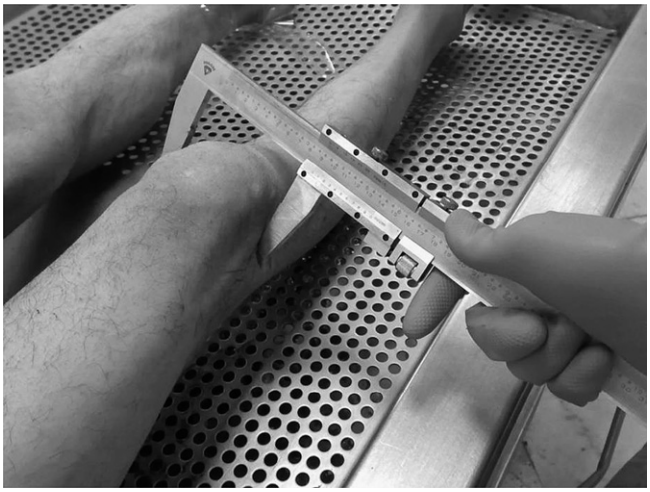


Fig. 1. Measurement of the maximum proximal width of the tibia.

2. Materials and methods

Since fusion of the tibia epiphyses occurs over the age of 20,[8–11] this study was carried out on the Iranian cadavers over the age of 20 with intact right side tibias being referred to the Autopsy Hall of Tehran Legal Medicine Organization (LMO) during 2009 and 2010.

Unknown corpses, burned bodies, skeletons, mutilated cases, and those with a history of fracture or bone surgery and congenital skeletal anomalies were excluded from the study. According to the following formulae of the sample size in correlation studies, the minimum sample size of 38 was obtained for males and females, since in the previous studies the lowest correlation coefficient between the dimensions and length of the tibia was 0.50 for men and women.[12]

$$n = \left[\frac{Z_\alpha + Z_\beta}{C}\right]$$

$$c = \frac{0}{5} \times l_n\left[\frac{(1+r)}{(1-r)}\right]$$

$$R = 0.50 \Rightarrow n = 38$$

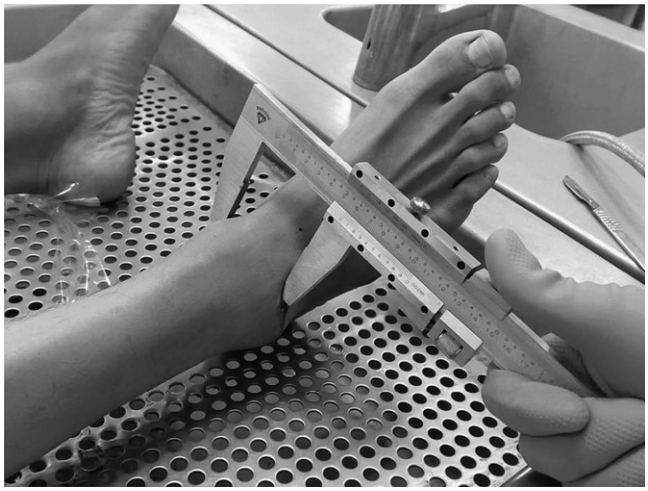


Fig. 2. Measurement of the maximum distal width of the tibia.

Fig. 3. Measurement of the maximum medial length of the tibia.

Thus, 40 tibias were examined for each gender. Written informed consent forms were obtained from the closest relatives and the ethical principles of Helsinki Declaration were followed. Then the bodies were placed supinely on the autopsy bed. Using a surgical knife, deep horizontal cuts were made to the bone on the surfaces of the medial (under interior ankle) and lateromedial parts of the ankle and the medial and lateral parts of the right knee. After the removal of soft tissues from the underlying bone, following parameters were measured using an industrial caliper with 0.02 mm precision:

- The maximum proximal width of the tibia: the maximum width of the bone between the medial and lateral condyles (Fig. 1)
- The maximum distal width of the tibia: the maximum width of the bone between the medial ankle and the fibular notch (Fig. 2)
- The maximum medial length of the tibia: the maximum length from the upper medial edge of the medial condyle of the tibia to the lower end of the medial ankle (Fig. 3)
- The maximum lateromedial length of the tibia: the maximum length from the lateral edge of the upper articular surface of the lateral condyle of the tibia to the tip of the medial ankle (Fig. 4)

Fig. 4. Measurement of the maximum lateromedial length of the tibia.

Table 1
Comparison of means, standard deviations, minimum and maximum of the tibia dimensions in terms of gender.

Dimensions / Gender	Maximum lateromedial length[a]				Maximum medial length[a]				Maximum distal width[a]				Maximum proximal width[a]			
	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum	Mean	Standard Deviation	Minimum	Maximum
Males	389.93	24.79	329.56	436.70	383.49	23.01	322.42	432.70	54.01	4.27	44.56	61.36	82.20	4.25	71.88	90.00
Females	346.31	20.33	310.38	388.24	339.45	20.79	307.64	386.74	50.65	3.36	45.32	58.68	74.11	4.36	64.24	82.92
Total	368.12	31.45	310.38	436.70	361.47	31.08	307.64	432.70	52.33	4.17	44.56	61.36	78.15	5.91	64.24	90.00

[a] All the measurements are in mm.

It must be mentioned that for precise measurements all the examinations were performed solely by the researchers and were repeated separately at least twice, and then their averages were recorded. After measuring the parameters, the skin was reconstructed. The obtained data were analyzed via the SPSS software (version 16) using frequency-descriptive tests and analytical tests including *t*-test and regression in order to evaluate any relationship between the length and width of the tibia.

3. Results

The mean age of the studied cadavers was 44.26 years with the standard deviation (SD) of 17.56 and the range of 20–87 years. The mean ages of the females and males were 46.47 with a 16.54 SD and 42.05 with an SD of 18.47 years, respectively. The minimum age for females and males was 20 while the maximum ages were 72 and 87 for females and males respectively. Table 1 shows the dimensions of the tibia in terms of gender.

To analyze the data, the Kolmogorov–Smirnov test (Lilliefors Significance Correction) was first applied to check the normality of the variables' distributions. The results showed that all the variables in both genders had normal distributions, and the distribution of age was normal as well. Therefore, *t*-test and regression models were applied to analyze the data.

T-test analyses showed that the means of the lengths of lateromedial and medial parts of the tibia and the widths of the distal and proximal parts of the bone were significantly higher than those in women with $p = 0.000$ (Graphs 1–4)

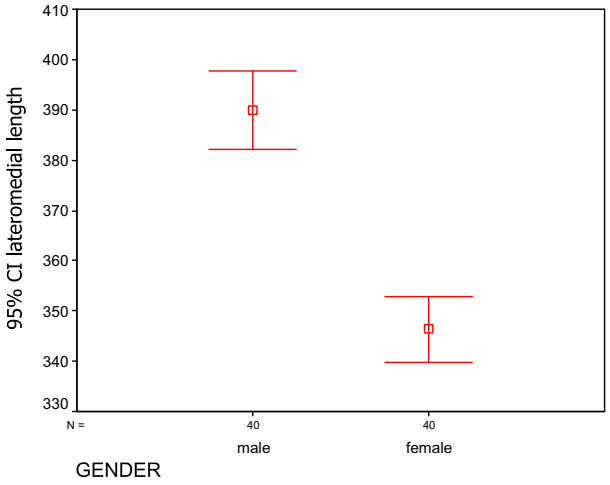
According to the formula for calculating mean of the maximum lateromedial length (MLML) in both sexes in the population with 95% confidence interval:

$$\text{Mean of MLML in the population } (\mu) = \overline{X}(\text{mean of MLML in sample}) \pm 2 \times \frac{S.D}{\sqrt{n}}$$

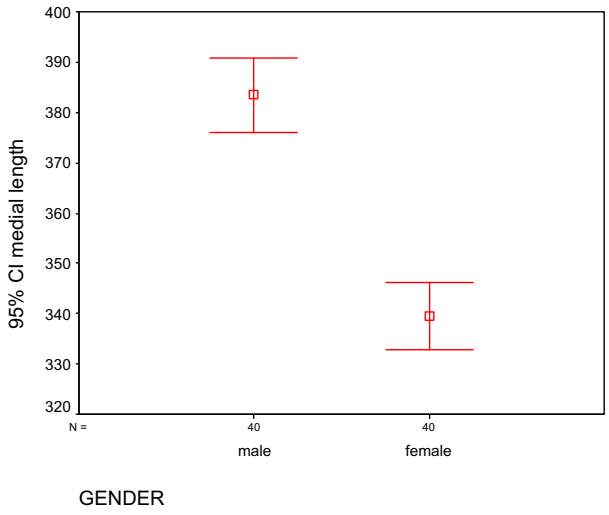
So for example upper & lower limit of the population mean for MLML in males with 95% confidence interval is 397.73 and 382.09 respectively

$$\left(\mu = 389.93 \pm 2 \times \frac{24.79}{\sqrt{40}}\right)$$

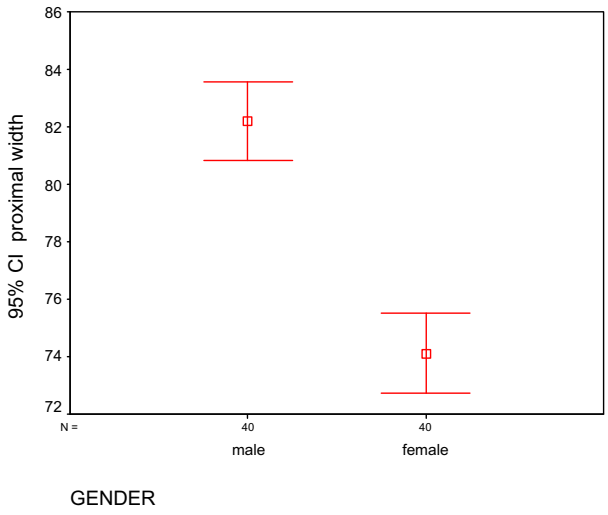
The index of dimorphism between the two sexes is obtained by



Graph 1. Comparison between the means of the maximum lateromedial length of the tibia in both genders in population with 95% confidence interval.



Graph 2. Comparison between the means of the maximum medial length of the tibia in both genders in population with 95% confidence interval.



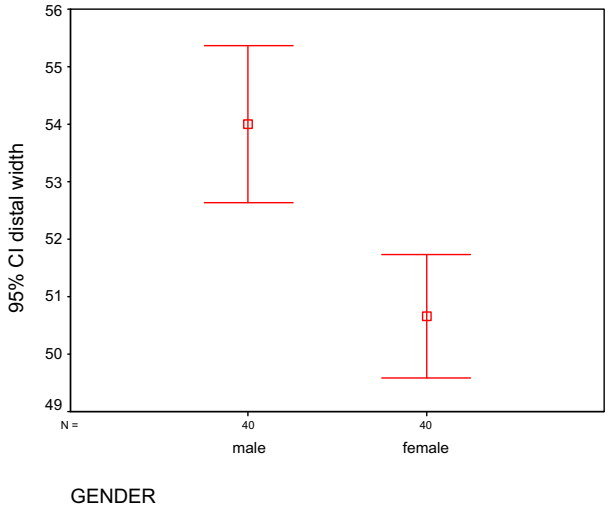
Graph 4. Comparison between the means of the maximum proximal width of the tibia in both genders in population with 95% confidence interval.

dividing the mean of each of the bone dimensions in men by the mean of the same dimension in women multiplied by 100.

$$\text{Index} = \text{Male M}/\text{Female M} \times 100$$

This index which is always higher than 100 indicates that men have larger tibial dimensions than women.[3] In our study, the indices of dimorphism for lateromedial length, medial length, proximal width, and distal width were 112.59, 112.97, 110.91, and 106.63 respectively.

Considering the average mean of each dimension mentioned for both genders as demarking point (dp), the sensitivity and specificity of each number were obtained using the ROC test for prediction of sex determination. Sensitivity and specificity are statistical measures of the performance of a binary classification test. Sensitivity measures the proportion of actual positives which are correctly identified. Specificity measures the proportion of negatives which are correctly identified.



Graph 3. Comparison between the means of the maximum distal width of the tibia in both genders in population with 95% confidence interval.

$$Sensitivity = \frac{number\ of\ True\ Positives}{number\ of\ True\ Positives + number\ of\ False\ Negatives}$$

$$Specificity = \frac{number\ of\ True\ Negatives}{number\ of\ True\ Negatives + number\ of\ False\ Positives}$$

The results of the comparison of sensitivity and specificity of the demarking point of each tibial dimension in sex determination are presented in Table 2. For example according to the dp obtained for MLML of tibia [359.75 mm], in general in 90% of males MLML will be more than this number and whenever the measurement of MLML is more than this dp, so with 80% probability, it belongs to the male.

The logistic regression was utilized for sex determination based on the mentioned variables so that gender could be identified by having only two variables of the medial length and the proximal width using the following formula:

$$G = (-0.076 \times \text{the maximum medial length of the bone in mm}) + (-0.370 \times \text{the maximum proximal width of the bone in mm}) + 56.110$$

If $G < 1.5$, the bone belongs to a male with a 95% probability, and if $G > 1.5$, the bone belongs to a female with a 95% probability.

Moreover, the correlations between age and other variables were studied. Generally, above the age of 20, age had a reverse correlation with the lateromedial length and the following equation was obtained between age and the lateromedial length:

$$\text{Age} = (-0.131 \times \text{the lateromedial length in mm}) + 92.623$$

Table 2
Comparison of sensitivity and specificity of the demarking point of each tibial dimension in sex determination.

Dimensions	[a]Demarking point (dp)	Sensitivity	Specificity
Lateromedial length	woman < 359.75 < man	90%	80%
Medial length	woman < 360.40 < man	90%	85%
Distal width	woman < 52.64 < man	67.5%	75%
Proximal width	woman < 79.11 < man	85%	87.5%

[a] The measurements are in mm.

Table 3
Comparison between similar studies on the tibia with the present study.

	Researchers	Year	Place	Methodology	Mean of lateromedial length (mm)		[a]ID of lateromedial length (%)	Mean of medial length (mm)		[a]ID of medial length (%)	Mean of proximal width (mm)		[a]ID of proximal width (mm)	Mean of distal width (mm)		[a]ID of distal width (mm)	Sex determination precision
					Males	Females		Males	Females		Males	Females		Males	Females		
1	The present study	2010	Iran	Fresh cadavers	389.93	346.31	112.59	383.49	339.45	112.97	82.20	74.11	110.91	54.01	50.65	106.63	67.5–90%
2	Chibba and Bidmos	2007	South Africa	Skeleton							75.7	68.7	110.18	49.6	45.5	109.01	
3	Salus and Tomicic	2004	Croatia	Skeleton	382.21	349.17											81.7–92.2%
4	El-Meligy et al.,	2004	Egypt	Living persons on the skin				387.8	348.5	110.95							
5	Didia and Nduka	2004	Nigeria	Living persons on the skin				466.6	411.4	113.41							
6	Ozaslan and Iscan	2001	Turkey	Living persons on the skin				383.7	351.3	109.22							
7	Reimers et al.,	1999	Spain	Skeleton				369.12	324.71	110.28	77.51	66.64	116.31	44.78	40.28	111.19	65–100%
8	Duyar and Penil	1999	Turkey	Living persons on the skin				389.85									
9	Mohanty	1997	India	Living persons on the skin				370.8	350.3	105.85							
10	Keiser et al.,	1992	Dart Collection	Skeleton													84.62–92%

[a] ID: Index of dimorphism.

The regression (R) in the equation was 0.235. Thus it must be noted that using a regression equation for age determination by bone dimensions is an approximate estimation and must be used with caution.

In order to determine the relationship between different dimensions of the tibia, the correlations between different dimensions were examined. Thus, the following formulae were obtained to determine the length of the tibia considering its width regardless of gender:

- *Lateromedial length of the tibia (mm) = (3.332 × the distal width in mm) + 193.77*
  - The regression (R) in this equation is 0.442.
- *Lateromedial length of the tibia (mm) = (3.632 × the proximal width in mm) + 84.251*
  - The regression (R) in this equation is 0.682.
- *Medial length of the tibia (mm) = (3.193 × the distal width in mm) + 187.796*
  - The regression (R) in this equation is 0.446.
- *Medial length of the tibia (mm) = (3.60 × the proximal width in mm) + 80.72*
  - The regression (R) in this equation is 0.685.

Thus, the maximum R is in the regression equation between the proximal width and the medial length of the tibia while the minimum R is in the regression equation between the distal width and the lateromedial length of the bone.

4. Discussion

An overview of the results of the present study and similar studies performed previously on the tibia is presented in Table 3.

A comparison between this study and the studies carried out by Slaus and Tomicic,[3] Mohanty,[10] Duyar and Penil,[13] Reimers et al.,[14] El-Meligy et al.,[15] and Didia and Nduka[16] reveals some differences in the bone dimensions that can be attributed to racial differences. Also according to the reviews done by the authors of this paper, the evaluation of the tibial dimensions has not been carried out directly on fresh corpses yet. Therefore, some differences observed between the results of our study with the studies conducted on dry skeletal bones or on the skin can be due to soft tissues including articular tissues and cartilages. The reason is that these tissues, despite efforts to remove them, partly adhere to bones. Moreover, skin and soft tissues in living persons in the mentioned studies preventing the accurate measurement of the bone can be considered as another reason.

The results of the study carried out by Ozaslan et al. showed that the mean of the medial length of the tibia in the Turkish males was approximately equal to the mean in our study and it would be predicted due to the racial similarities.[17] However, the mean of the length of the tibia in the Turkish females is higher than that in the females of our study and this difference may be justified by some reasons including the genetic factors, appropriate nutrition, and physical activity level. The index of dimorphism (ID) for the medial length of the tibia in our study was more than that in Ozaslan et al.'s study carried out on the Turkish population.[17]

The index of dimorphism obtained for the maximum medial length in our study was 112.97. The index was 105.85 in Mohanty's study,[10] 110.95 in El-Meligy et al.'s,[15] 113.41 in Didia and Nduka's,[16] 109.22 in Ozaslan et al.'s,[17] and 110.28 in Reimers et al.'s studies.[14] Thus, comparing the indices of dimorphism, indicating the morphological differences between men and women, reveals the lowest ID for Indians (105.85) and the highest ID for Nigerians (113.41). The indices higher than 100 can be used in sex determination as a better criterion. In our study, the ID for the medial

length and lateromedial length of the tibia was 112.97 and 112.59, respectively. These indices are higher than those in all other studies (with the exception of the study in Nigeria), and it seems that the racial differences are the most remarkable reasons. On the other hand, in addition to gender differences, the difference in the length of tibia of males and females in the present study can be attributed to genetic factors, appropriate nutrition, and lower relevant physical activity. Compared to other studies, the tibial length in the females of our study was lower than those in the other studies (even Indians) whereas the tibial length in the males was higher than or equal to those in most of the other studies.

In our study, the value of the medial length of the tibia was found to be better in sex determination and hence it can be desirably used for Iranians.

In total, a comparison between this study and the studies by Chibba and Bidmos,[12] and Reimers et al.[14] shows that the proximal and distal widths of the tibia in Iranian corpses are more than those in Europeans including the Hispanic population. Racial differences, in addition to the way of studying fresh corpses, seem to be an important factor in making the difference. The index of dimorphism obtained for the proximal width of the tibia was 110.91 in this study. The indices were 110.18 for Chibba and Bidmos's study[12] and 116.31 for Reimers et al.'s study.[14] Therefore, the ID for the proximal width of the tibia for the Iranian population is lower than that for the Hispanic population, but it is more than that for South Africans residents from European descents. On the other hand, the ID for the distal width in our study was lower than that in Reimers et al.'s as well as Chibba and Bidmos's studies.

The highest index of dimorphism in our study was found for the medial length of the tibia with a difference equal to 12.97% while the lowest recorded rate for the ID of the distal width was with a 6.63% difference. Consequently, the best dimension that can be used for the tibial differentiation in men and women is the medial length followed by the lateromedial length, the proximal width, and the distal width respectively.

In a study conducted by Iscan et al. on South African whites, the distal width of the femur and tibia presented the best sex discrimination with a precision mean of 86–91% and a slightly higher precision in women than in men.[18] In Reimers et al's study carried out on the skeletal bones of the Hispanic population, the transverse thickness, the epiphyseal proximal width and the minimum circumference of the shaft showed the highest diagnostic power.[14] The obtained equations indicated high precision means in the range of 94.9–98.3% with a 100% precision in women. When the equations were reapplied on the Hispanic population, their precision was in the range of 65–94.7% and with a precision of 80–100% in women.[14] In a study by Keiser et al. on the skeletons of the blacks and whites, the measurements of the proximal tibia showed a sex determination precision of 84.62–92%.[19] In the study by Slaus and Tomicic, it was found that six variables with a precision of 92.9%, two variables with slightly lower precisions of 91.7 and 87.8%, and one variable with a precision rate of 85.6 and 81.7% could determine genders.[3]

Like other conducted studies, in our research all the four dimensions had appropriate precisions in sex determination, and significant relationships were found between the bone dimensions via correlations. In Chibba and Bidmos's study, the observed correlation range between the dimensions and the tibia length was 0.57and 0.70 for women and 0.50 to 0.52 for men.[12] In our study, the correlation coefficients between the lateromedial length with the proximal and distal widths in all the studied population were 0.682 and 0.442 respectively, and between the medial length with the proximal and distal widths in all the studied population the coefficients were 0.685 and 0.446 respectively. Moreover, the coefficients between the lateromedial length with the medial length, the proximal and distal widths of the tibia in men were 0.985, 0.545, and 0.380 respectively while the coefficients between the medial length, with the proximal and distal widths of the tibia in men were 0.561and 0.440 respectively. Additionally, the coefficient between the proximal and the distal widths of the tibia in men was found to be 0.572. Consequently, the highest correlation coefficient in the regression equation between length and width was found between the proximal width and the medial length of the tibia, being 0.682 in all the population and 0.561 in the men, while the lowest correlation coefficient in the regression equation was found between the proximal width and the lateromedial length of the tibia, being 0.442 in all of the population and 0.380 in the men.

According to the results of this study, it can be concluded that the sex of an adult can be guessed using the anthropometric parameters of the tibia with a high precision, but also the approximate length of the bone and consequently the stature of a person can be estimated when, due to different reasons, only a piece of the tibia is available.

According to the low regression equation (0.235) between age and maximum lateromedial tibial length, these parameters aren't useful for age prediction.

This research was done on Iranian cadavers in Legal Medicine Organization. Legal Medicine Organization of Iran with more than 1.5 million clinical forensic referrals and 50 000 autopsies per year is an appropriate field for such researches and trainings.[20–35]

Conflict of interests

We have no competing interests.

Funding

We had no financial support for this research. The research was done in the framework of the thesis of Dr. Navid Khosravi (Forensic Medicine Assistant of the Tehran University of Medical Sciences) during routine forensic autopsies on the fresh cadavers referred to Tehran's LMO.

Ethical approval

Written informed consent forms were completed by the close relatives of the deceased, and they were assured that all the secrets and information about the bodies were fully confidential. The ethical principles of the Helsinki Declaration were respected by the authors. The forms were signed by the relatives in all steps when the measurements of the lengths and widths were to be done.

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